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Short communication. Effects of storage time and boiling on root tuber colour in two sweet potato [*Ipomoea batatas* L. (Lam.)] cultivars

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Abstract

The aim of this work was to determine the effect of storage time and boiling on the colour of sweet potato (cvs. Morada INTA and Regal) root tubers. Increasing storage time more strongly reduced the skin chroma (C*) of raw Morada INTA tubers than that of raw Regal root tubers. The skin hue angle (Hº) of raw Morada INTA tubers increased linearly with storage time; at the end of the experiment values were almost twice those at baseline. The results of this study suggest that the perception of skin-Hº is influenced by C*. In both cultivars, storage time more strongly affected the colour variables of the boiled than the raw flesh. Boiling led to a reduction in flesh luminosity (L*) and an increase in flesh-Hº. The interaction between cultivar and storage time appears to regulate the C* and Hº values of orange-flesh cultivars.

Key words: L*, C*, H°, sweet potato skin, sweet potato flesh.

Resumen

Nota corta. La duración del almacenamiento y la cocción afectan al color de las raíces de reserva de dos cultivares de batata, *Ipomoea batatas* L. (Lam.)

Los objetivos de este trabajo fueron determinar el efecto de la duración del almacenamiento y el estado de cocción (cruda o hervida) sobre el color de las raíces tuberosas de dos cultivares de batata (Morada INTA y Regal). El tiempo de almacenamiento tuvo un mayor efecto sobre el color de la piel de Morada INTA que sobre Regal. Independientemente del cultivar, el efecto del almacenamiento fue reducir la saturación (C*) del color de la piel. El ángulo de color (H°) o tono aumentó linealmente con la duración del almacenamiento sólo para Morada INTA, siendo casi el doble al término del experimento que al comienzo. Los resultados de este estudio sugieren que la percepción del tono (H°) de la piel está afectada por la intensidad del color (C*). La mayoría de los efectos de los tratamientos sobre el color de la pulpa fueron detectados en raíces hervidas. El hervido causa una disminución en la luminosidad (L*) y un incremento en H°, independientemente del cultivar. La interacción entre el cultivar y la duración del almacenamiento regula los valores de C* y H° de la pulpa en los cultivares de color anaranjado.

Palabras clave: boniato, L*, C*, H°, piel, pulpa.

Colour is an important feature of fresh fruits and vegetables. It is usually the main attribute that consumers take into consideration when deciding whether to purchase such produce (Marsili, 1996). Skin and flesh colour are important in the visual appeal of sweet potatoes; the flesh colour of steamed sweet potatoes is probably a good indicator of their general acceptability (Villareal *et al*., 1979). From a health point of view, there is increasing evidence that the pigments responsible for sweet potato colour may have a positive effect on human well-being (Cevallos-Casals and Cisneros-Zevallos, 2002; Yamakawa and Yoshimoto, 2002).

No reports have been published on the effect of storage time on sweet potato skin colour variables such as lightness (L*), a*, b*, chroma (C*) and hue (H°). Miyazaki (1995) reported that the absorbance (525 nm) of HCl-methanol periderm extracts of four sweet potato cultivars (a measure of their colour) decreased by 20-30% after storage at 13°C for six months. Colour was also lost during curing; high humidity also made

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the skins lighter. These results suggest that storage can affect sweet potato skin colour.

Anthocyanins are responsible for the skin colour of red and purple sweet potatoes (Yoshinaga *et al.,* 1999), and a negative correlation has been found between soil temperature and anthocyanin content in cv. Ayamurasaki tubers (Kobayashi *et al*., 1998). This suggests that temperature modulates the colour variables of purple-skinned sweet potatoes. This has been confirmed in cvs. Jewel and Copper Skin Jewel sweet potatoes; soil warming increases the colour intensity of the epidermis (Sanders *et al*., 1981).

With respect to flesh color, values for the L*, a*, and b* components of cooked orange-coloured sweet potatoes were found to decrease after 10 days of storage (Sistrunk, 1977). Discoloration was also detected by a panel of sensorial quality experts. Changes in colour over the storage period could affect consumer acceptability.

The aim of the present work was to determine the effects of storage time and boiling on the colour variables L*, C* and H° of the root tubers of two sweet potato cultivars with different flesh colours and textures: cvs. Morada INTA and Regal.

Morada INTA and Regal sweet potatoes were grown according to commercial practices at the San Pedro Agricultural Experiment Station (San Pedro, Buenos Aires, 33° 41' S, 59° 41' W). All were harvested in April 2001. Morada INTA has a purple skin and dry, yellow flesh. Regal has brilliant purplish-red skin and moist, orange flesh (Jones *et al*., 1985). The effect of storage time (0 to 2 months) on the skin colour of the two cultivars, and of storage time and boiling on their flesh colour, were determined. A two month storage period was chosen since most growers in Argentina store sweet potato tubers for this length of time.

After harvest, all tubers were cured at 29°C for one week. Five tubers (200-300 g tuber^{-1}) per cultivar were then washed and allowed to dry at room temperature. L*, a*, and b* were then determined for the raw and boiled skin and the flesh. For storage purposes, two five-tuber lots per cultivar were chosen at random from the remaining root tubers. Each lot was placed in a plastic mesh bag and maintained in a storage chamber under recommended storage conditions (15°C and relative humidity > 90%). The colour variables of one lot per cultivar were analysed after one and then two months of storage.

At the end of storage, the tubers were boiled in a pan with tap water for 30 min. A total of 30 sweet potato tubers were eventually examined since the same samples were assessed both before and after boiling.

For both raw and boiled tubers, colour was measured using a Minolta chromameter. The diameter of the measuring area was 8 mm; the standard illuminant C ($Y_0 = 100$, $X_0 = 98.072$, $Z_0 = 118.225$) was used as a reference. C* and H° were calculated according to McGuire (1992). Two replicates were performed for all skin and flesh colour determinations. Flesh readings were taken on transversally cut tubers. In previous work (Martí, 2003) it was determined that by testing 5 roots, and by taking 2 readings per root, differences in skin-L*, skin-C* and skin-H° of less than 6.37, 3.30, and 11.34 respectively could not be detected. The corresponding limits for the flesh were 4.47, 3.21, and 2.30. Data were analysed in a factorial manner [with 5 replicates (tubers) and 2 readings nested within replications], using the GLM procedure (SAS, 1987). The significance of the change (linear or quadratic) in colour variables over time was determined by orthogonal comparisons.

A significant interaction was seen between storage time and cultivar with respect to skin-C* and skin-H°. The skin-L* of neither cultivar was affected by storage time. Storage time had little influence on the skin colour variables of Regal tubers, but significantly affected the C* and H° of Morada INTA tubers. The only significant effect of storage time on Regal tubers was on skin-C*, which decreased linearly as time increased (Table 1). After two months, the colour of the tubers in the storage chamber was less saturated (more greyish) than at the beginning of the experiment.

Table 1. Effect of storage time on lightness (L*), colour saturation (C*) and hue (H°) of Regal and Morada INTA sweet potato skins

Variable	Month 0[1]	Month 1[1]	Month 2[1]	SE (n = 10)	Trend[2]
Regal					
L*	50.1a	49.3a	52.3a	1.20	*Ns*
C*	27.7a	25.8a	22.6a	1.42	*Li**
H°	58.5a	56.3a	62.1a	1.71	*Ns*
Morada INTA					
L*	42.7b	44.3b	43.0b	0.73	*Ns*
C*	25.5a	20.4b	19.5b	0.63	*Li**, Q***
H°	33.6b	44.8b	56.4b	1.83	*Li****

SE: standard error of the mean. [1] Mean of 5 roots, 2 readings per root. [2] Significance of the trend over time. *Li:* linear. *Q:* quadratic. *, **, ***: significant at the 5, 1, and 0.1% levels respectively. *Ns:* not significant. a,b: significance of the difference between cultivars with respect to months (F test, 5%).

The magnitude of the storage time-induced changes in the skin of the Morada INTA tubers was greatest for H°. Regardless of storage time, the skin-L* values of the Regal tubers were higher than those of the Morada INTA tubers (Table 1).

The skin-C* values of the Morada INTA tubers decreased over time in a quadratic fashion (Table 1). After two months, these tubers had a skin-C* value 11% lower than at the beginning of the experiment. At this earlier point the cultivars showed no differences in skin-C*, but after one month of storage the Morada INTA tubers became more greyish than the Regal tubers.

The skin-H° of the Morada INTA tubers increased linearly over time (Table 1). After two months of storage the values were almost twice as high as at the beginning of the storage period. This shows that the tubers turned from a red colour, at the beginning of the experiment, to the orange range of colours after two months of storage. The skin-H° of the Regal tubers was 10 -18% higher (more orange) than that of the Morada INTA tubers, regardless of storage time.

The three way interaction *cultivar x storage time x boiling* had a significant effect on cooked flesh-L* and flesh-C* (Table 2), while the interactions *storage*

Table 2. ANOVA table for the effect of cultivar, storage time and boiling on flesh colour variables

Source	DF	SS	MS	F value	Pr > F
Lightness (L*)					
Cultivar	1	2,918.76	2,918.76	278.55	***
Time	2	40.56	20.28	1.94	*Ns*
Boiling	1	18,149.88	2,918.76	1,732.13	***
Cultivar x Time	2	68.56	34.28	3.27	*
Cultivar x Boiling	1	109.90	109.90	10.49	**
Time x Boiling	2	17.21	8.60	0.82	*Ns*
Cultivar x Time x Boiling	2	83.27	41.63	3.97	*
Replication	4	25.76	6.44	0.61	*Ns*
Reading (Replication)	5	4.43	0.88	0.08	*Ns*
Error	99	1,037.35	10.47		
Saturation (C*)					
Cultivar	1	3,720.43	3,720.43	401.39	***
Time	2	226.30	113.15	12.21	***
Boiling	1	2,531.20	2,531.20	273.09	***
Cultivar x Time	2	51.18	25.59	2.76	*Ns*
Cultivar x Boiling	1	1,169.31	1,169.31	126.16	***
Time x Boiling	2	34.05	17.02	1.84	*Ns*
Cultivar x Time x Boiling	2	65.11	32.55	3.51	*
Replication	4	47.26	11.82	1.27	*Ns*
Reading(Replication)	5	13.07	2.61	0.28	*Ns*
Error	99	917.61	9.27		
Hue Angle (H°)					
Cultivar	1	22,152.24	22,152.24	5,487.51	***
Time	2	154.66	77.33	19.16	***
Boiling	1	3,944.07	3,944.07	977.02	***
Cultivar x Time	2	17.47	8.74	2.16	*Ns*
Cultivar x Boiling	1	75.02	75.02	18.58	***
Time x Boiling	2	31.48	15.74	3.90	*
Cultivar x Time x Boiling	2	0.48	0.24	0.06	*Ns*
Replication	4	31.80	7.95	1.97	*Ns*
Reading (Replication)	5	15.79	3.16	0.78	*Ns*
Error	99	399.65	4.04		

*, **, ***: significant at the 5, 1, and 0.1% levels, respectively. *Ns*: not significant. DF: degrees of freedom. SS: Sum of squares. MS: Mean squares. Pr > F: P-value for the F test (probability to have a F value greater than the corresponding table-F value).

Table 3. Effect of storage time, cultivar and boiling on lightness (L*), colour intensity (C*), and hue (H°)

Variable	Month 0[1]		Month 1[1]		Month 2[1]		SE (n = 10)		Trend[2]	
	Boiled[3]	*Raw*	*Boiled*	*Raw*	*Boiled*	*Raw*	*Boiled*	*Raw*	*Boiled*	*Raw*
Regal										
L	49.6b[4]	71.0b	47.0b	71.0b	49.3b	72.0b	0.60	0.56	*Q***	*Ns*
C*	39.0a	54.8a	40.4a	53.6a	34.8a	52.1a	0.81	0.83	*Li**, Q***	*Ns*
H°	69.4b	60.8b	71.8b	61.2b	72.1b	61.6b	0.69	0.20	*Li**	*Ns*
Morada INTA										
L	53.3a	83.2a	58.1a	83.0a	58.3a	83.1a	1.87	0.59	*Ns*	*Ns*
C*	33.9b	39.2b	32.6b	35.4b	33.0a	33.7b	1.15	1.14	*Ns*	*Li***
H°	96.9a	85.4a	101.1a	87.0a	101.5a	87.9a	0.48	0.97	*Li***,Q***	*Ns*

SE: standard error of the mean. [1] Mean of 5 roots and 2 readings per root. [2] Significance of the trend on time. [3] For Regal tubers, differences between boiled and raw were all significant (5%). For Morada INTA tubers, the only non-significant differences between boiled and raw were for C* at Month 1 and Month 2. [4] Significance of the difference between cultivars with respect to each combination of month and cooking status (F test, 5 %). Li: linear, Q: quadratic, *, **, ***: significant at the 5, 1, and 0.1% levels respectively. *Ns:* not significant.

time x boiling and *cultivar x boiling* had a significant effect on flesh-H° (Table 2). Table 3 shows the breakdown of these interactions and indicates that storage time had a greater influence on the flesh colour of the boiled tubers. Significant effects on raw tubers were only found with respect to Morada INTA flesh-C*. Flesh-L* decreased by about 30-35% with boiling, regardless of cultivar or storage time (Table 3). This means that tubers become darker after boiling. A significant quadratic effect of storage time was seen on flesh-L* in the boiled Regal tubers, though the differences were negligible from a practical standpoint. No significant effect of time was seen on the flesh-L* of Morada INTA roots (either raw or boiled). Regardless of storage time, these values were always higher than those of the Regal tubers. Boiling caused a 30-35% decrease in flesh-C* in Regal tubers (Table 3). For this cultivar, the flesh-C* of the boiled tubers showed a significant quadratic trend with respect to storage time, with values 14% lower than at the beginning of the experiment. The flesh-C* values of raw Regal tubers were not affected by storage time. Boiled Morada INTA tubers showed lower flesh-C* values than their raw counterparts, though differences decreased with storage time. The flesh-C* of boiled Morada INTA tubers did not vary with storage time, but that of the raw tubers decreased by 14% after two months: at this time the flesh-C* values of both boiled and raw tubers were the same. Regal tubers always showed higher flesh-C* values than Morada INTA tubers, the difference being greater for raw tubers (28-35%) than for boiled tubers (5-19%).

For both cultivars, boiling caused an increase in the flesh-H° over that of raw tubers, regardless of storage time (Table 3). Regal tuber flesh changed colour, turning from orange towards the yellow range, while Morada INTA tuber flesh colour changed from yellow towards the green range. In boiled Regal tubers, flesh-H° increased linearly over time, though the magnitude of the changes was small (< 4%). No storage time effect was detected on flesh-H° values in raw Regal tubers. In boiled Morada INTA tubers, flesh-H° increased after one month of storage and then remained constant. Again, the increase was small (4.5%). Storage time had no effect on raw Morada INTA tubers in this respect. As expected, raw and boiled Regal tuber flesh-H° remained in the orange colour range, significantly different to that of the Morada INTA tubers with colours in the yellow range.

The changes in sweet potato skin colour seen in this study may be due to changes in anthocyanin content. Anthocyanins are the main pigments in the skin of red and purple sweet potato cultivars (Yoshinaga, 1998; Cevallos-Casals and Cisneros-Zevallos, 2002). Genotypic diversity with respect to sweet potato anthocyanin content has been recorded (Yoshinaga, 1998; Yoshinaga *et al.,* 1999); the differences in skin colour recorded in the present work may reflect such genotypic diversity. The fact that the skin-L* values for the raw Regal tubers were higher than those of the Morada INTA tubers (Table 1) agrees with previous reports which describe the skin of the former as «brilliant purplish-red» (Jones *et al.*, 1985), while that of the latter is described as «pale purple» (Martí, 2003).

Changes in anthocyanin content during storage have been seen in strawberries, raspberries and blueberries (Kalt *et al*., 1999), cranberries (Wang and Stretch, 2001) and blood oranges (Rapisarda *et al*., 2001). The stability of anthocyanins from sweet potato extracts depends on temperature, light levels and pH (Cevallos-Casals and Cisneros-Zevallos, 2003). Changes in colour expression (C* and H°) in sweet potato extracts can arise through changes in anthocyanin structure and pH (Stintzing *et al.,* 2002; Cevallos-Casals and Cisneros-Zevallos, 2003). The reduction in absorbance at 525 nm detected by Miyazaki (1992) in periderm extracts after 6 months of storage at 13°C may be due to changes in the concentration or structure of these anthocyanins. The changes seen in the present study may therefore be due to changes in pigment concentration owed to the synthesis or degradation of pigments, changes in their chemical structure, and/or changes in environmental factors. Further studies are required to determine the exact nature of the changes in sweet potato skin colour during storage.

Most of the skin colour changes that occurred in this study can be perceived by the human eye; humans can detect differences in skin C* and H° as small as 3.4 units (Martí, 2003). The storage-induced changes in skin-H° in the Morada INTA tubers were the most noticeable. It remains to be determined what effects these changes may have on consumer acceptability. As mentioned above, Regal H° has been described as «brilliant purplish-red» (Jones *et al*., 1985). However, in the present study, it was not in the purple range (0°/360°) but in the red range close to orange (Table 1). The same has been reported for other cultivars previously classified as red, purple-red or purple, but which were found to have average Hº values of 37.93°, 47.00°, and 50.40° respectively (Martí, 2003). In both the former and the present study, the skin-C* of all of the cultivars was in the lowest third of the corresponding scale, reflecting a low C* or high proportion of grey. It has been postulated that the human eye is sensitive primarily to H° differences, followed by C*, and finally L* (Marsili, 1996). Though the results of this study suggest that H° perception is affected by C*, at low C* values H° discrimination would be poor, and the H° of the skin of many clones described as purple may be in fact a highly unsaturated red. These findings suggest that a colour index combining colour variables, such as those developed for other fruits, is needed to better describe the skin colour of sweet potatoes.

The literature contains no reports on the changes in colour variables for dry, yellow-flesh sweet potatoes during storage. The effect of storage time on boiled Regal tuber flesh-L* recorded in the present work disagrees with that reported by Sistrunk (1977). The latter authors reported increased discoloration with increasing storage time, as shown by lower flesh-L* values and higher discoloration scores (awarded by experts in sensorial qualities) in two types of boiled and baked orange-flesh sweet potatoes. No such change was recorded in the present study. This discrepancy may be due to the cultivars used, the length of the storage period (1-2 months compared to 10 days) and the storage conditions. Cultivar differences in terms of susceptibility to discoloration were also detected by Sistrunk (1977). The flesh-C* values calculated by these authors showed they decreased as storage time increased from 0 to 10 days, regardless of storage temperature (2 or 24°C). The data obtained in the present study are in partial agreement with this since a decrease in the flesh-C* of boiled Regal tubers was detected only after 2 months. The same is concluded when comparing the boiled Regal flesh Hº results of the present study with Sistrunk's data, which showed an increase in Hº with increasing storage time. These findings suggest that interactions between cultivar and storage length regulate the flesh-C* and H° values of boiled, orange-flesh sweet potatoes as a result of pigment changes.

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References

CEVALLOS-CASALS B.A., CISNEROS-ZEVALLOS L.A., 2002. Bioactive and functional properties of purple sweet potatoes (*Ipomoea batatas* (L) (Lam.). Acta Hort 583, 195-203.

CEVALLOS-CASALS B.A., CISNEROS-ZEVALLOS L.A., 2003. Stability of anthocyanin-based aqueous extracts of Andean purple corn and red-fleshed sweet potato compared to synthetic and natural colorants. Food Chem 86, 69-77.

JONES A., DUKES P.D., SCHALK J.M., HAMILTON M.G., MULLEN M.A., BAUMGARDNER R.A., PATERSON D.R., BOSWELL D.E., 1985. 'Regal' sweet potato. HortScience 20(4), 781-782.

KALT W., FORNEY C.F., MARTIN A., PRIOR R.L., 1999. Antioxidant capacity, vitamin C, phenolics, and anthocyanins after fresh storage of small fruits. J Agr Food Chem 47, 4638-4644.

KOBAYASHI T., IKOMA H., MOCHIDA H., 1998. Effect of cultural conditions on anthocyanin content of purple-colored sweetpotato. Sweetpotato Research Front, No. 6 [on line]. Available in: http://ss.knaes.affrc.go.jp/sporf/no06/contents.html [3 Nov, 2000].

MARSILI R., 1996. Food color: more than meets the eye. Food product design [on line]. Available in: http://www.foodproductdesign.com/archive/1996/1096QA.html [3 November, 2003].

MARTÍ H.R., 2003. Estimation of sample size in skin and flesh color measurements of dry flesh sweetpotato [*Ipomoea batatas* L (Lam.)]. Sci Hort 98, 331-336.

MCGUIRE R.G., 1992. Reporting of objective color measurements. HortScience 27(12), 1254-1255.

MIYAZAKI T., 1995. Surface color and anthocyanins in the periderm of sweet potato (*Ipomoea batatas* L.). J Japan Soc Hortic Sci 61(1), 191-197 [In Japanese].

RAPISARDA P., BELLOMO S.E., INTELISANO S., 2001. Storage temperature effects on blood orange fruit quality. J Agr Food Chem 49, 3230-3235.

SANDERS D.C., PORTER W.C., SKAGGS R.W., SCHEIRER D.M., 1981. Growth, development, and root quality of sweet potato as influenced by soil warming. HortScience 16(4), 537-539.

SAS, 1987. SAS/STAT guide for personal computers. Version 6. SAS Institute Inc., Cary, NC, USA.

SISTRUNK W.A., 1977. Relationship of storage, handling, and cooking method to color, hardcore tissue, and carbohydrate composition in sweetpotatoes. J Amer Soc Hort Sci 102(4), 381-384.

STINTZING F.C., STINTZING A.S., CARLE R., FREL B., WROLSTAD R.E., 2002. Color and antioxidant properties of cyaniding-based anthocyanin pigments. J Agr Food Chem 50, 6172-6181.

VILLAREAL R.L., TSOU S.C.S., LAI S.H., CHIU S.L., 1979. Selection criteria for eating quality in steamed sweet potato roots. J Amer Soc Hort Sci 104(1), 31-33.

WANG S.Y., STRETCH A.W., 2001. Antioxidant capacity in cranberry is influenced by cultivar and storage temperature. J Agr Food Chem 49, 969-974.

YAMAKAWA O., YOSHIMOTO M., 2002. Sweetpotato as food material with physiological functions. Acta Hort 583, 179-185.

YOSHINAGA M., 1998. Breeding of purple-fleshed sweetpotato. Proc. Intnl. Workshop on Sweetpotato Production System Towards the 21st Century. Miyakonojo, Japan. Kyushu National Agricultural Experiment Station.

YOSHINAGA M., YAMAKAWA O., NAKATANI M., 1999. Genotypic diversity of anthocyanin content and composition in purple-fleshed sweet potato [*Ipomoea batatas* (L.) Lam]. Breeding Sci 49(1), 43-47.